

allows cutting the bone without substantially impairing the periostium. In this case there will be new bone growth that fills the gap between the two stumps. Often the need arises for implanting longer and longer rods, each time requiring a new surgical intervention. This is the case in particular for young patients, still at the growing age, where the lengthening of the rod must match the natural growth of the other limbs.

Summary of the Invention

The invention is a rod-type prosthesis that can be lengthened without surgery. It requires surgery only once when the prosthesis is first implanted. It avoids the need for subsequent surgical procedures to lengthen the rod. Instead, lengthening is accomplished in a non-invasive manner by means of an externally applied magnetic field that acts on one or several magnets located inside the prosthesis. The externally applied magnetic field is designed to rotate the magnet or magnets, which in turn rotate one or several screws or other such mechanism that produce the lengthening of the rod. The external magnetic field is generated by a magnetic apparatus which forms a part of this invention.

Lengthening of the rod allows new, natural bone growth to occur to fill the gap between the two bone stumps that result from surgically removing the diseased portion of the bone.

The external magnetic apparatus surrounds the limb with the prosthesis. Two different versions of this apparatus are described. In one version, the apparatus consists principally of one or several permanent magnets or electromagnets. The latter, when activated, are supplied by direct current. The apparatus can be rotated mechanically around the limb, either by hand or by an electric motor. Conventional slip rings and electric brushes allow the current to be supplied by a power supply that can be stationary.

In the second version, the apparatus consists of at least four electromagnets, each being activated by the discharge of a capacitor or capacitor bank, producing short pulses of current and associated magnetic fields, sufficient to rotate the permanent magnet in the prosthesis by 90 degrees or a fraction thereof each time the current pulses are applied. In this second version, there is no need for a mechanical rotation of the apparatus around the limb, since the capacitor discharges are timed to produce the required magnetic field rotation electrically rather than mechanically.

Brief Description of the Drawings

FIG. 1 is a lengthwise section of the expansible rod-type prosthesis. It illustrates the prosthesis in its shortest length.

FIG. 2 is a lengthwise section of the same prosthesis in its most extended length.

FIG. 3 is an enlarged section, taken perpendicular to the axis of the rod, of a ratchet mechanism. This ratchet is designed to prevent a reduction in the length of the prosthesis when subjected to the variable loads acting on the limb in actual wear.

FIG. 4 shows the principal elements of the first version of the external magnetic apparatus.

FIG. 5 shows the principal elements of the second version of the external magnetic apparatus.

FIG. 6 is the basic electrical diagram for the capacitor discharges into one of the electromagnets in the second version of the external magnetic apparatus.

FIG. 7 is a diagram that shows the current pulses in four solenoids S_1 to S_4 as a function of the time t in the second version of the external magnetic apparatus.

FIG. 8 is a hysteresis diagram of a permanent magnet in the prosthesis.

Detailed Description of the Preferred Embodiment

In FIG. 1 there is a single, rod-shaped permanent magnet designated by 1. Its direction of magnetization is perpendicular to its axis. Preferred type magnets are rare-earth permanent magnets, coated to be biocompatible. Other possible materials are platinum-cobalt alloys, or, less expensively, ferrites or Alnico. The shaft 2, which can be a Chrome-Nickel steel, is attached by adhesive to the permanent magnet 1 and has at its ends two screws 3 that engage the internal threads on the two tubular structures 4. The preferred material for these are titanium alloys or other non-ferromagnetic alloys that allow the external magnetic field from the external magnetic apparatus to penetrate to the permanent magnet of the prosthesis. The thread between 3 and 4 can be coated with Teflon or lubricated with a biocompatible lubricant such as graphite powder. 5 is a ratchet mechanism, shown enlarged in FIG. 3. The cap 6 serves to facilitate the assembly. The bone, for instance a femur, is shown in outline as 7.

FIG. 2 shows the same prosthesis as FIG. 1, but now in its fully expanded position. 1 to 7 are the same components as in FIG. 1. Where the new growth of the bone has occurred when the prosthesis has been expanded, is shown by 8. It is understood that the length of the prosthesis and therefore the length of the new growth can be anything between the extremes shown in FIGS. 1 and 2, respectively.

FIG. 3 is an enlarged section, taken perpendicular to the axis of the rod, of the ratchet mechanism that serves to prevent the rod from getting shorter when subjected to variable loads from motions by the patient. 2 is a continuation of the shaft and is connected by adhesive or similar means to the permanent magnet. 4 is part of the tubular

structure that is also shown in FIGS. 1 and 2. The component 9 is an elastomer with prongs that engage 2. As shown, the combination of 2 and 9 permit rotation of 2 in a counter-clockwise direction that produces a lengthening of the prosthesis, but prevents rotation in the clockwise direction that would cause a shortening of the prosthesis. This type of ratchet is particularly well suited for prostheses with a small diameter, typical of rod-type prostheses. It is understood, however, that a conventional, metallic racket with spring loaded prongs could also be used.

FIG. 4 is a section and view of the external magnetic apparatus, version 1, taken crosswise to the limb of the patient. This apparatus incorporates one or several electromagnets, powered with direct current, with soft iron cores 10 and electric windings 11. The soft iron pole pieces 12 produce the external magnetic field that interacts with the permanent magnet in the prosthesis. The directions of the current in the windings 11 are such as to produce a magnetic North in one of the pole pieces and South in the other. The tube 13 contains the limb of the patient. The assembly, other than 13, is supported by rollers 14 and can be rotated either by hand or by an electric motor around the limb. Slip rings 15 combined with conventional electric brushes that are stationary transmit the current from a stationary direct current power supply to the electromagnets. The rollers 14 run on a stationary ring 16 that is supported by the structural member 17 that is attached to a table on which rests the patient.

FIG. 5 represents a second version of the external magnetic apparatus. In this version, the electromagnets, having cores 10 and windings 11, are powered by short, but intense current pulses. There are at least four electromagnets, here labeled by S_1 to S_4 . The directions of the currents in the winding change from pulse to pulse in such a manner

that the same pole piece 12 can be a magnetic North or South. The effect of switching the current directions in the electromagnets is such as to produce an external magnetic field that rotates in space by 90 degrees, inducing a corresponding rotation of the permanent magnet in the prosthesis. The components 13 and 17 are the same as in FIG. 4. There are at four Hall-current sensors 18 that sense the magnetic field of the permanent magnet in the prosthesis and allow the physician to determine the rotational position of the permanent magnet in the prosthesis without need for x-ray examination. To avoid interference from the more intensive external magnetic field, these sensors are activated only between the current pulses.

Although somewhat more complicated than version 1, there are two advantages to version 2. First, the peak currents in a compact device can be much larger than the direct currents in version 1, resulting in a larger torque exerted on the permanent magnet in the prosthesis, which in turn produces a larger force available for the expansion. Because of the short duration of the pulses, with longer pauses between pulses, high peak currents can be tolerated without overheating the windings of the electromagnets. Second, the external magnetic apparatus is simplified since it does not require the mechanical rotation about the patient's limb.

FIG. 6 is an electrical circuit diagram that shows the charging, via a resistor R , and discharging of a capacitor C . The double switch S is either open, or closed to direct the current into the electromagnet L in one direction, or closed to direct the current in the opposite direction. Such circuits can be used separately for each of the electromagnets shown in FIG. 5.

FIG. 7 is a timing diagram for the current pulses, I , that activate the